US009209875B2

(12) **United States Patent**
Gaal et al.

(10) **Patent No.: US 9,209,875 B2**
(45) **Date of Patent: Dec. 8, 2015**

(54) **STRUCTURED MIMO CODEBOOK**

(71) Applicant: **QUALCOMM INCORPORATED**, San Diego, CA (US)

(72) Inventors: **Peter Gaal**, San Diego, CA (US); **Stefan Geirhofer**, Brooklyn, NY (US); **Juan Montojo**, San Diego, CA (US)

(73) Assignee: **QUALCOMM INCORPORATED**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/512,223**

(22) Filed: **Oct. 10, 2014**

(65) **Prior Publication Data**

US 2015/0036761 A1 Feb. 5, 2015

Related U.S. Application Data

(62) Division of application No. 13/167,209, filed on Jun. 23, 2011, now Pat. No. 8,891,652.

(60) Provisional application No. 61/358,368, filed on Jun. 24, 2010.

(51) **Int. Cl.**
H04B 7/02 (2006.01)
H04L 1/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04B 7/0456*** (2013.01); ***H04B 7/0469*** (2013.01); ***H04B 7/063*** (2013.01); ***H04B 7/0615*** (2013.01); *H04B 7/0465* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04B 7/0456
USPC 375/267, 346, 347, 348, 299
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,594,226 B1 7/2003 Benning et al.
8,254,487 B2 * 8/2012 Tsai et al. 375/267
(Continued)

FOREIGN PATENT DOCUMENTS

EP 2037646 A2 3/2009
JP 2004201337 A 7/2004
(Continued)

OTHER PUBLICATIONS

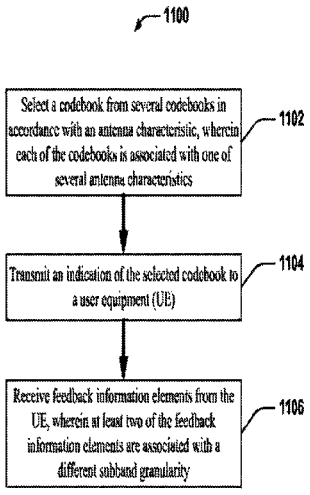
Catt: "Codebook design for 8Tx DL MIMO," 3GPP TSG RAN WG1 meeting #59b, R1-100022, 3rd Generation Partnership Project (3GPP), Valencia, Spain, Jan. 18-22, 2010, 7 pages.
(Continued)

Primary Examiner — Qutbuddin Ghulamali
(74) *Attorney, Agent, or Firm* — Seyfarth Shaw LLP

(57) **ABSTRACT**

Provided is a method of wireless communication which includes selecting a codebook from a plurality of codebooks in accordance with an antenna characteristic, and transmitting an indication of the selected codebook. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics. In some designs, channel state information is received from a user equipment. The channel state information may be used to determine downlink scheduling and/or precoding. In some designs, the channel state information may include feedback elements associated with different subband granularity. The feedback elements may also indicate a selection of a subset of precoder column vectors and/or a phase offset between two groups of transmit antennas.

21 Claims, 14 Drawing Sheets



(51) **Int. Cl.**
H04B 7/04 (2006.01)
H04B 7/06 (2006.01)

(52) **U.S. Cl.**
CPC *H04B7/0478* (2013.01); *H04B 7/0626* (2013.01); *H04B 7/0658* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,259,835	B2	9/2012	Kim	
2009/0041140	A1	2/2009	Xiao et al.	
2009/0041150	A1	2/2009	Tsai et al.	
2009/0080549	A1	3/2009	Khan et al.	
2009/0109873	A1	4/2009	Shen et al.	
2009/0122857	A1	5/2009	Li et al.	
2009/0316610	A1	12/2009	Yellin et al.	
2010/0118817	A1	5/2010	Damnjanovic et al.	
2011/0080969	A1*	4/2011	Jongren et al.	375/267
2012/0027113	A1	2/2012	Gaal et al.	

FOREIGN PATENT DOCUMENTS

JP	2008104193	A	5/2008
JP	2008519565	A	6/2008
JP	2009071825	A	4/2009
JP	2010500790	A	1/2010
JP	2011188295	A	9/2011
JP	2013502111	A	1/2013
JP	2013520122	A	5/2013
WO	2006052501	A1	5/2006
WO	2008004835	A2	1/2008
WO	2008118067	A2	10/2008
WO	2009096708	A1	8/2009
WO	2009125956	A1	10/2009
WO	2009134357	A1	11/2009
WO	2010024543	A2	3/2010
WO	WO 2010024543	A2 *	3/2010
WO	2011017991	A1	2/2011
WO	2011098975	A1	8/2011

OTHER PUBLICATIONS

Ericsson, "Refinements of Feedback and Codebook Design," 3GPP TSG-RAN WG1 #61, R1-102630, Montreal, Canada, May 10-14, 2010, 11 pages.

Ericsson, ST-Ericsson: "A Flexible Feedback Concept," 3GPP TSG-RAN WG1 #59bis, R1-100051, 3rd Generation Partnership Project, Valencia, Spain, Jan. 18-22, 2010, 5 pages.

International Search Report and Written Opinion-PCT/US2011/041819-ISA/EPO-Feb. 14, 2012.

Motorola: "4-Tx Codebook Design and Performance Comparison", 3GPP TSG-RAN WG1 Meeting #58b, Oct. 12, 2009, R1-093964, pp. 28.

Panasonic: "8Tx Codebook Design," 3GPP TSG RAN WG1 Meeting #60bis, R1-102460, Beijing, China, Apr. 12-16, 2010, pp. 1-7.

Pantech: "On the two stage 8 Tx codebook," 3GPP TSG-RAN WG1 Meeting #61b, Jun. 22, 2010, R1-103616, pp. 2.

Partial International Search Report-PCT/US2011/041819, ISA/EPO-Oct. 6, 2011.

QUALCOMM Inc., "Codebook Design for DL LTE-A MIMO operation," 3GPP TSG-RAN WG1 #59bis, R1-101490, 3rd Generation Partnership Project, San Francisco, USA, Feb. 22-26, 2010, 7 pages.

QUALCOMM Inc: "Codebook Design for DL LTE-A operation", 3GPP Draft; R1-100753, 3rd Generation Partnership Project (3GPP), Mobile Competence Centre ; 650, Route Des Lucioles ; F-06921 Sophia-Antipolis Cedex ; France, vol. RAN WGI, no. Valencia, Spain; 20100118, Jan. 21, 2010, XP050418387, [retrieved on Jan. 21, 2010].

QUALCOMM Inc., "Explicit feedback in support of MU-MIMO operation," 3GPP TSG-RAN WG1 #59bis, R1-100685, 3rd Generation Partnership Project, Valencia, Spain, Jan. 18-22, 2010, 3 pages.

QUALCOMM Inc., "Extending the UE feedback for efficient MU-MIMO," 3GPP TSG-RAN WG1 #59bis, R1-101488, 3rd Generation Partnership Project, San Francisco, USA, Feb. 22-26, 2010, 9 pages.

QUALCOMM Inc., "Extending the UE feedback for efficient MU-MIMO and CoMP," 3GPP TSG-RAN WG1 #59bis, R1-100684, 3rd Generation Partnership Project, Valencia, Spain, Jan. 18-22, 2010, 5 pages.

Samsung, "8Tx Codebook Design for Channel Feedback in support of DL SU-MIMO in LTE-A," 3GPP TSG RAN WG1 Meeting #59bis, R1-100119, 3rd Generation Partnership Project, Valencia, Spain, Jan. 18-22, 2010, 16 pages.

Samsung, "Views on the feedback framework for Rel. 10," 3GPP TSG RAN WG1 Meeting #61, R1-103377, 3rd Generation Partnership Project, Montreal, Canada, May 10-14, 2010, 17 pages.

Texas Instruments: "8Tx Codebook Design," 3GPP TSG-RAN WG1 Meeting #61b, Jun. 22, 2010, R1-103701, pp. 7.

Texas Instruments: "Possible Refinement on 8Tx Codebook Design", 3GPP TSG-RAN WG1 Meeting #60b, Apr. 12, 2010, R1-102104, pp. 8.

ZTE: "Codebook Design for E-UTRA MIMO," 3GPP TSG-RAN WG1 #47bis, R1-070202, Jan. 15-19, 2007, pp. 1-6.

ZTE, "DL Codebook Design for 8 Tx MIMO in LTE-A," 3GPP TSG RAN WG1 Meeting #59bis, R1-100531, 3rd Generation Partnership Project, Valencia, Spain, Jan. 20-26, 2010, 8 pages.

* cited by examiner

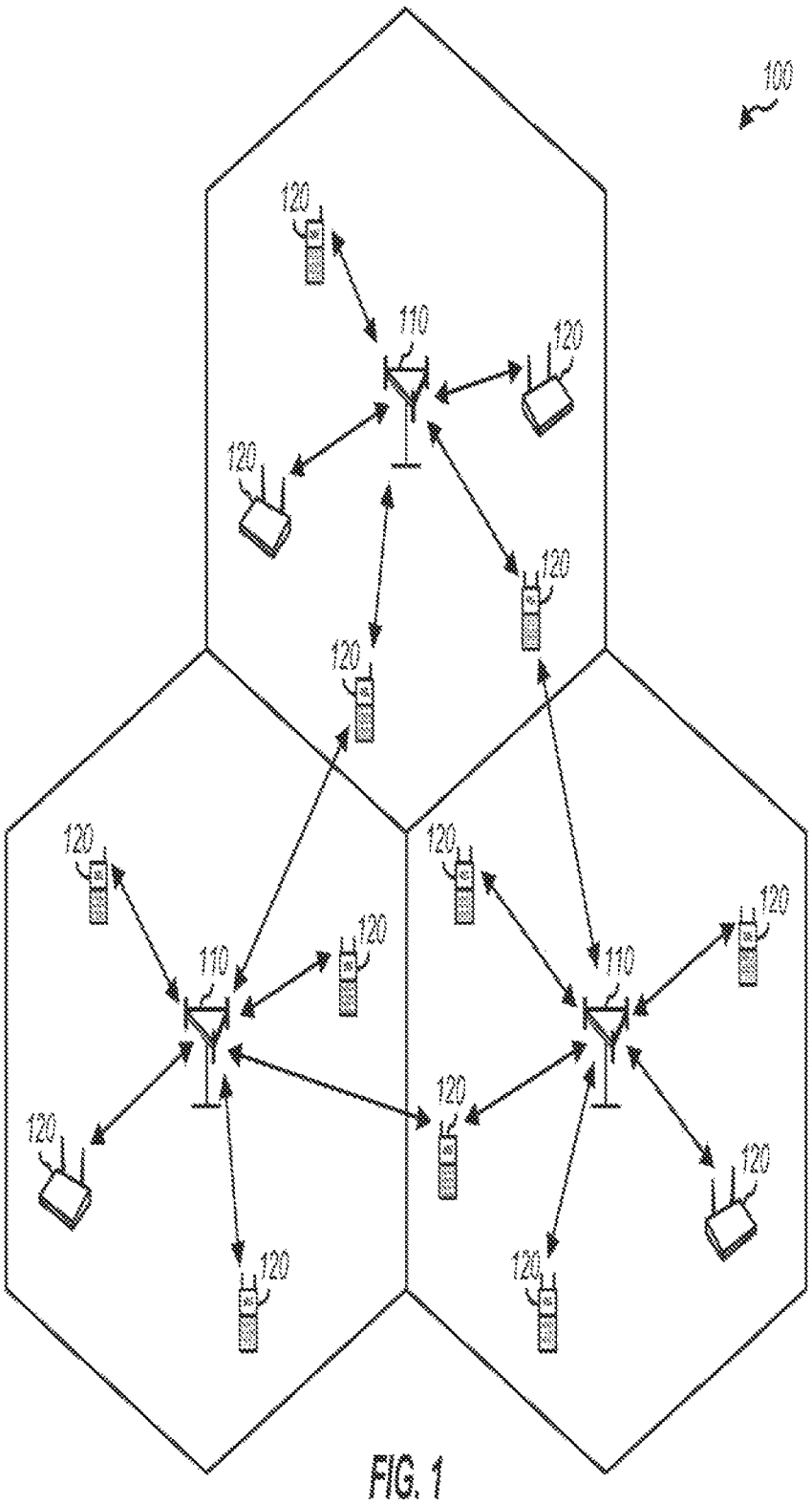


FIG. 1

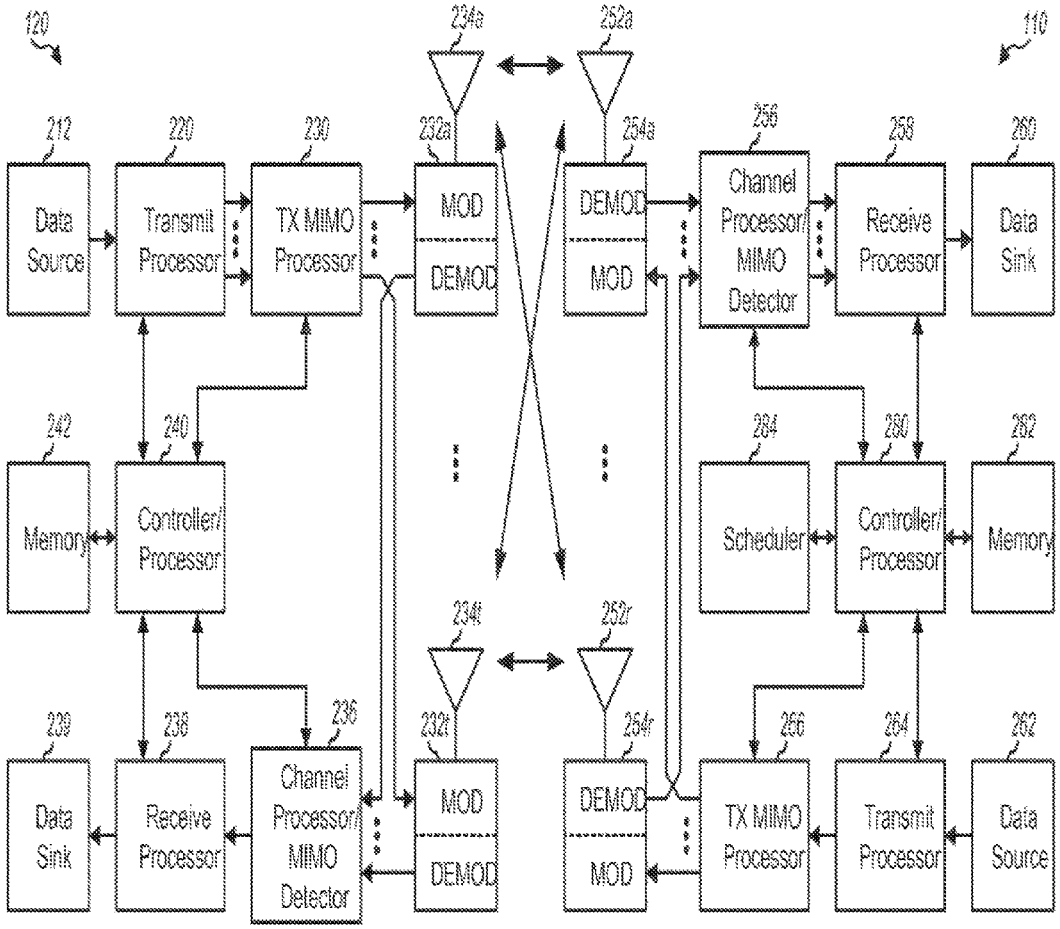

120
110
234a
252a
212
220
230
232a
254a
256
258
260
Data Source
Transmit Processor
TX MIMO Processor
MOD
DEMOD
DEMOD
MOD
Channel Processor/ MIMO Detector
Receive Processor
Data Sink
242
240
284
280
282
Memory
Controller/ Processor
Scheduler
Controller/ Processor
Memory
234t
252r
239
236
232t
254r
266
264
262
Data Sink
Receive Processor
Channel Processor/ MIMO Detector
MOD
DEMOD
DEMOD
MOD
TX MIMO Processor
Transmit Processor
Data Source
200

FIG. 2

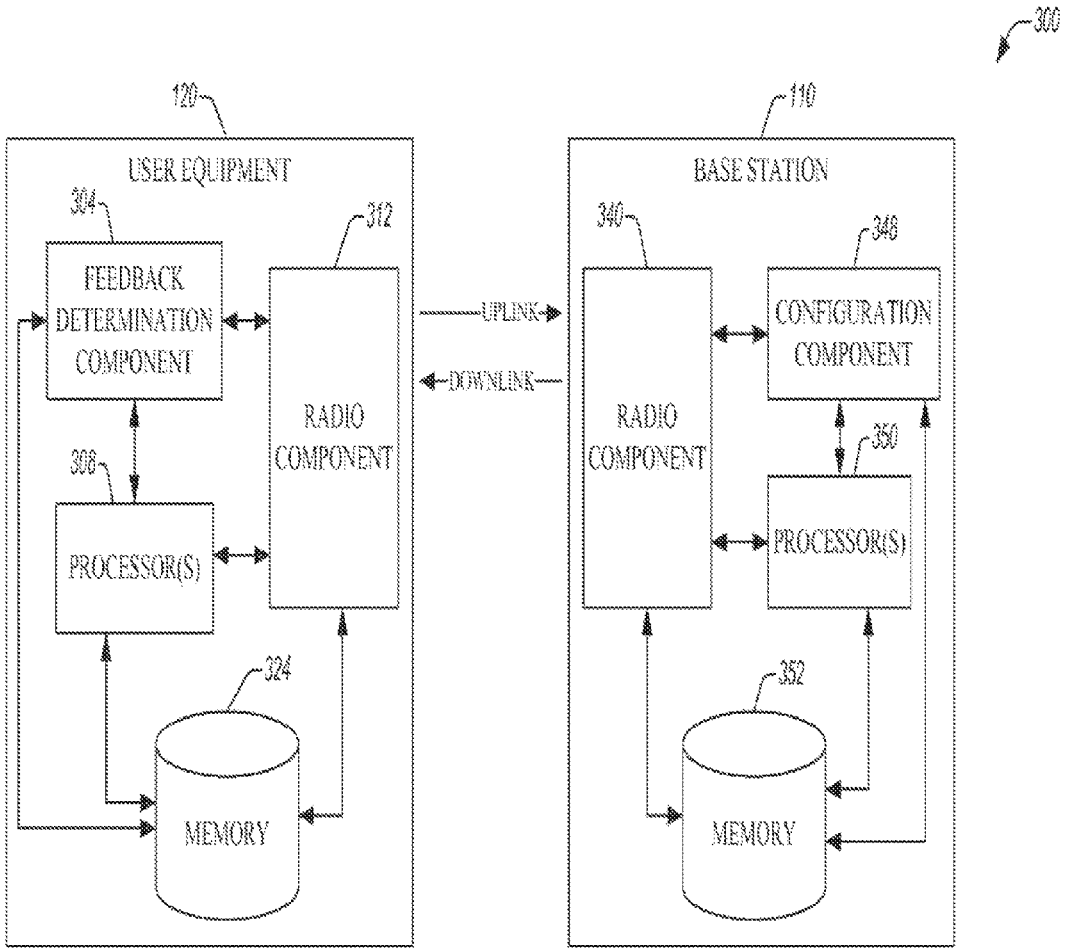

300
120
USER EQUIPMENT
304
FEEDBACK DETERMINATION COMPONENT
312
RADIO COMPONENT
306
PROCESSOR(S)
324
MEMORY
UPLINK
DOWNLINK
110
BASE STATION
340
RADIO COMPONENT
348
CONFIGURATION COMPONENT
350
PROCESSOR(S)
352
MEMORY

FIG. 3

FIG. 4A

FIG. 4B

FIG. 4C

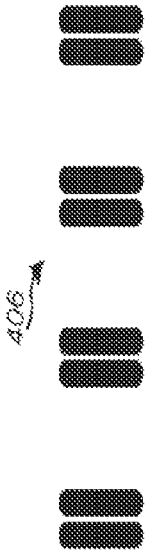


FIG. 4D

FIG. 4E

FIG. 4F

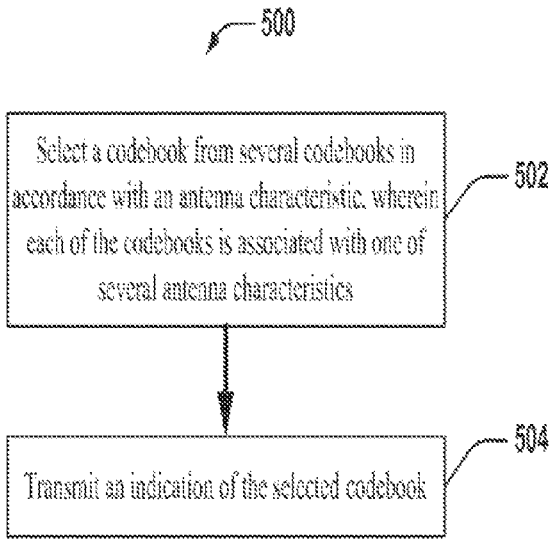

500
Select a codebook from several codebooks in accordance with an antenna characteristic, wherein each of the codebooks is associated with one of several antenna characteristics
502
Transmit an indication of the selected codebook
504

FIG. 5

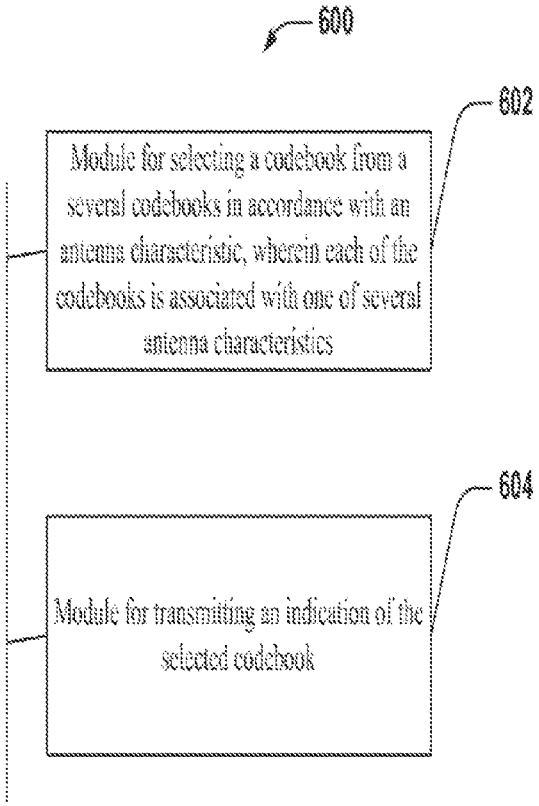

600
Module for selecting a codebook from a several codebooks in accordance with an antenna characteristic, wherein each of the codebooks is associated with one of several antenna characteristics
602
Module for transmitting an indication of the selected codebook
604

FIG. 6

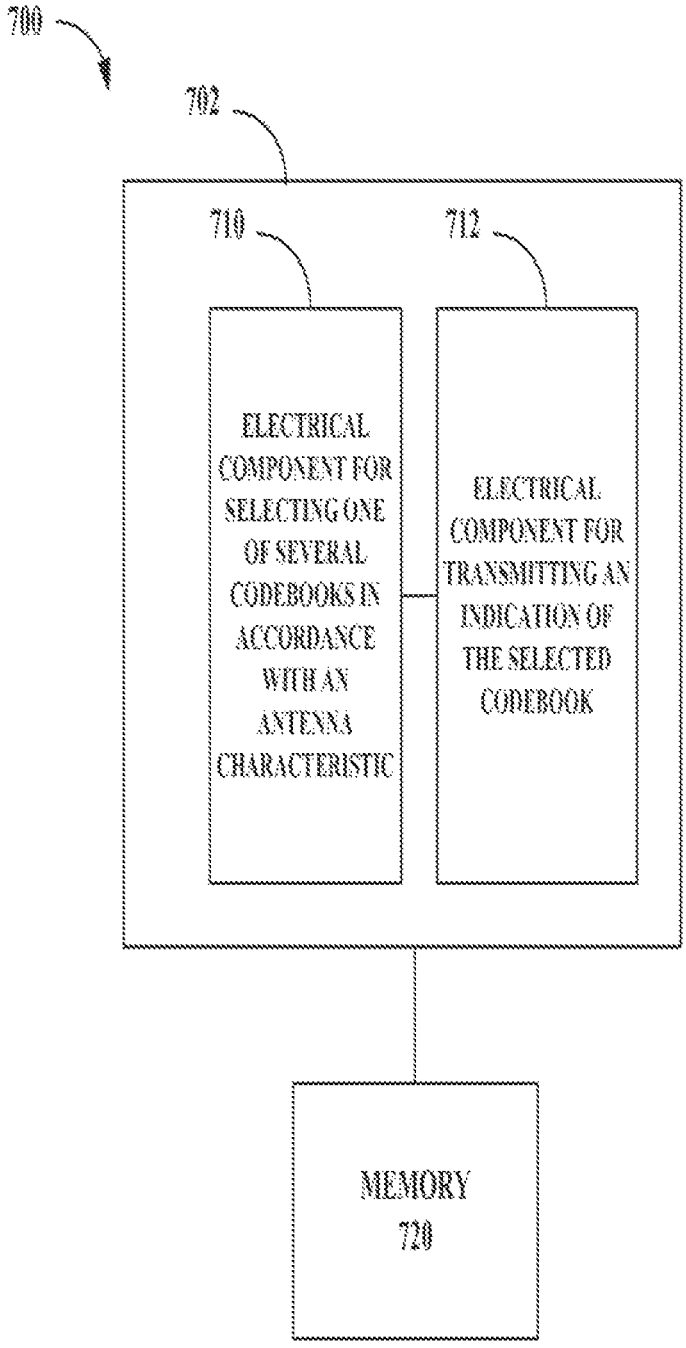

700
702
710
712
ELECTRICAL COMPONENT FOR SELECTING ONE OF SEVERAL CODEBOOKS IN ACCORDANCE WITH AN ANTENNA CHARACTERISTIC
ELECTRICAL COMPONENT FOR TRANSMITTING AN INDICATION OF THE SELECTED CODEBOOK
MEMORY 720

FIG. 7

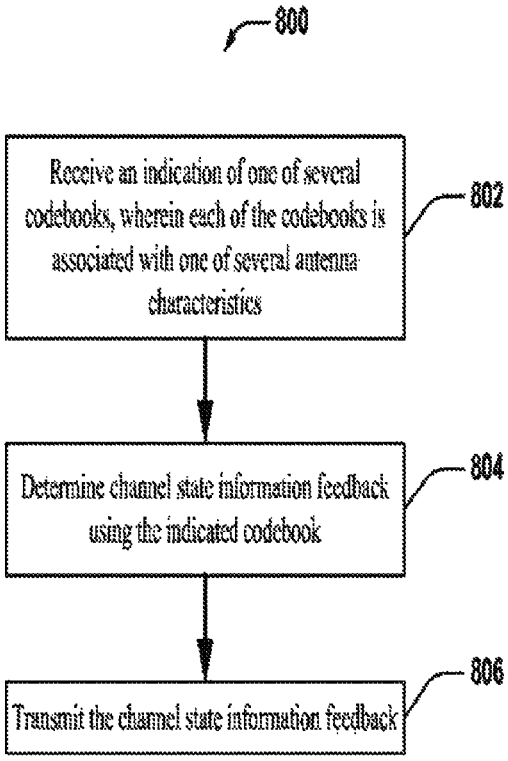

800
Receive an indication of one of several codebooks, wherein each of the codebooks is associated with one of several antenna characteristics
802
Determine channel state information feedback using the indicated codebook
804
Transmit the channel state information feedback
806

FIG. 8

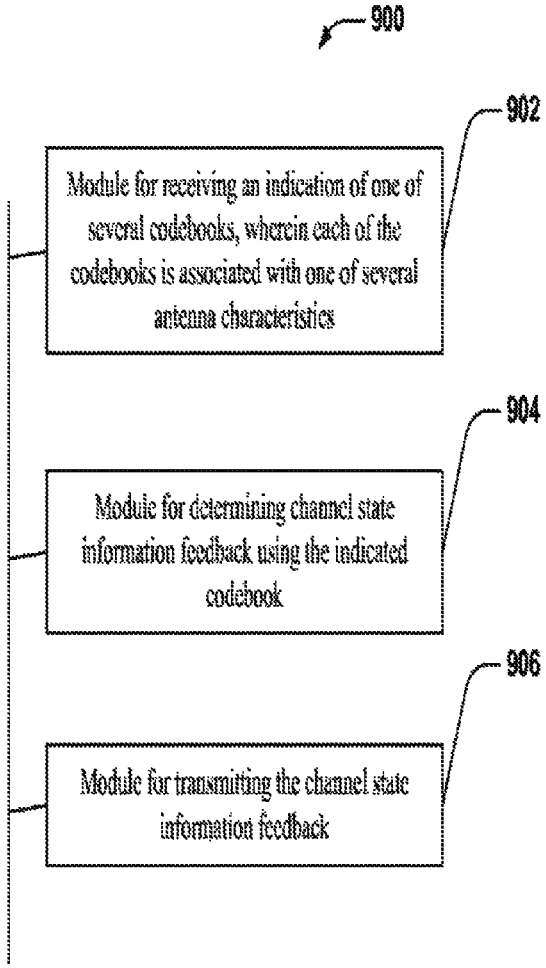

900
Module for receiving an indication of one of several codebooks, wherein each of the codebooks is associated with one of several antenna characteristics
902
Module for determining channel state information feedback using the indicated codebook
904
Module for transmitting the channel state information feedback
906

FIG. 9

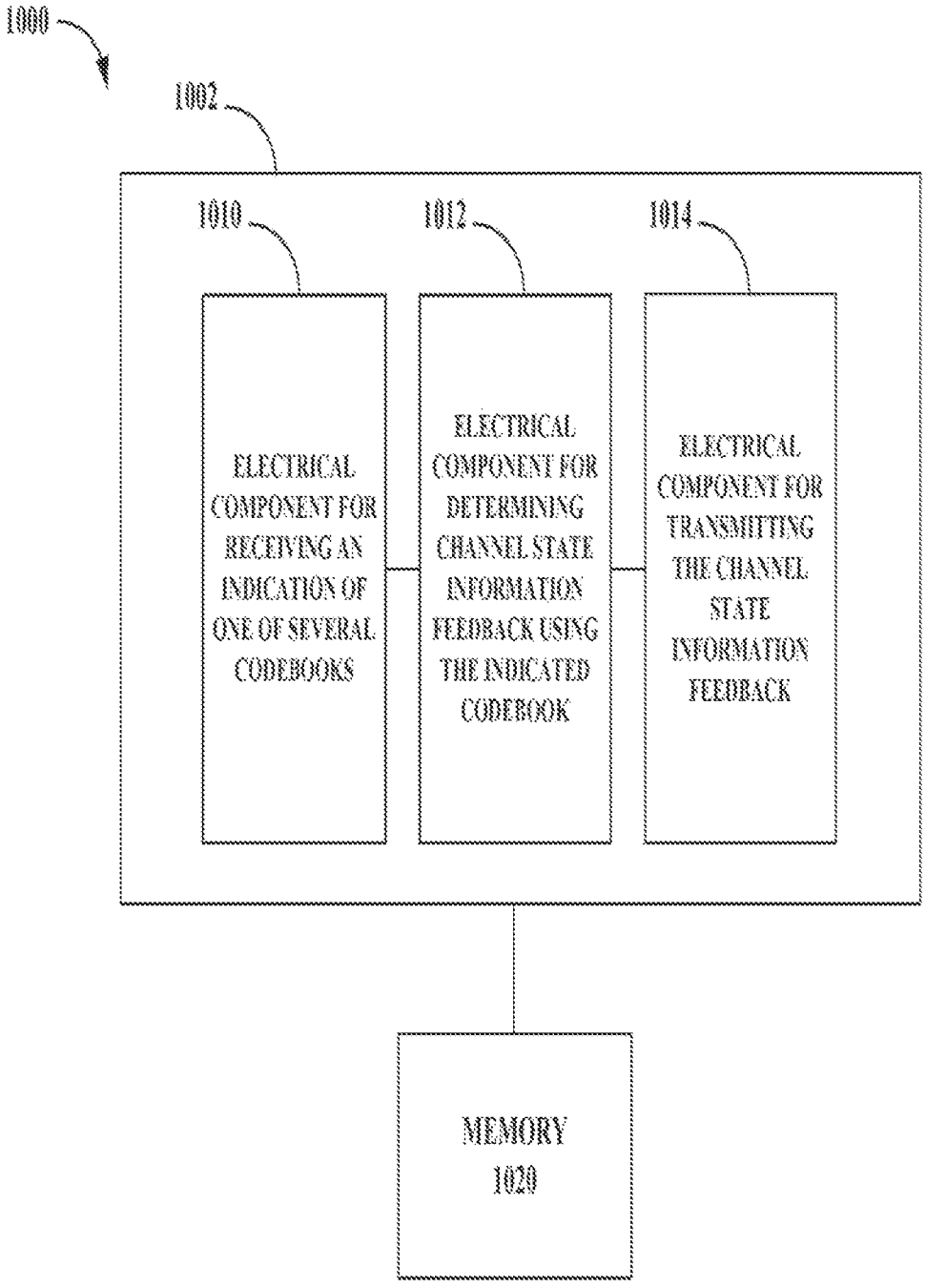

1000
1002
1010
1012
1014
ELECTRICAL COMPONENT FOR RECEIVING AN INDICATION OF ONE OF SEVERAL CODEBOOKS
ELECTRICAL COMPONENT FOR DETERMINING CHANNEL STATE INFORMATION FEEDBACK USING THE INDICATED CODEBOOK
ELECTRICAL COMPONENT FOR TRANSMITTING THE CHANNEL STATE INFORMATION FEEDBACK
MEMORY 1020

FIG. 10

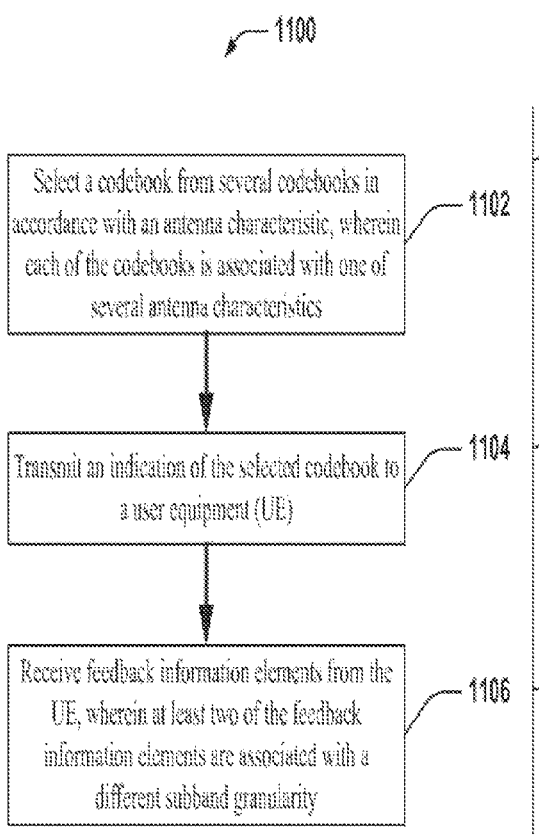

1100
Select a codebook from several codebooks in accordance with an antenna characteristic, wherein each of the codebooks is associated with one of several antenna characteristics
1102
Transmit an indication of the selected codebook to a user equipment (UE)
1104
Receive feedback information elements from the UE, wherein at least two of the feedback information elements are associated with a different subband granularity
1106

FIG. 11

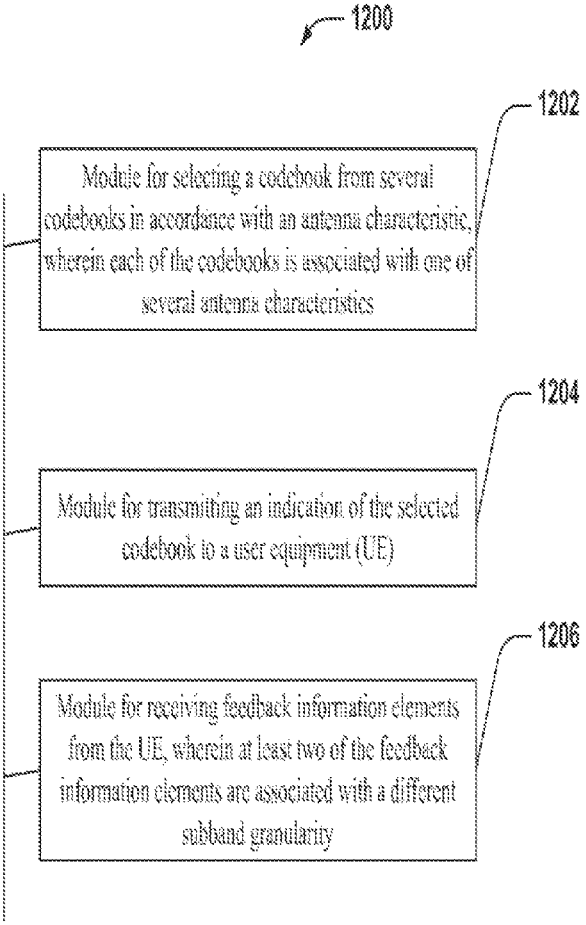

1200
Module for selecting a codebook from several codebooks in accordance with an antenna characteristic, wherein each of the codebooks is associated with one of several antenna characteristics
1202
Module for transmitting an indication of the selected codebook to a user equipment (UE)
1204
Module for receiving feedback information elements from the UE, wherein at least two of the feedback information elements are associated with a different subband granularity
1206

FIG. 12

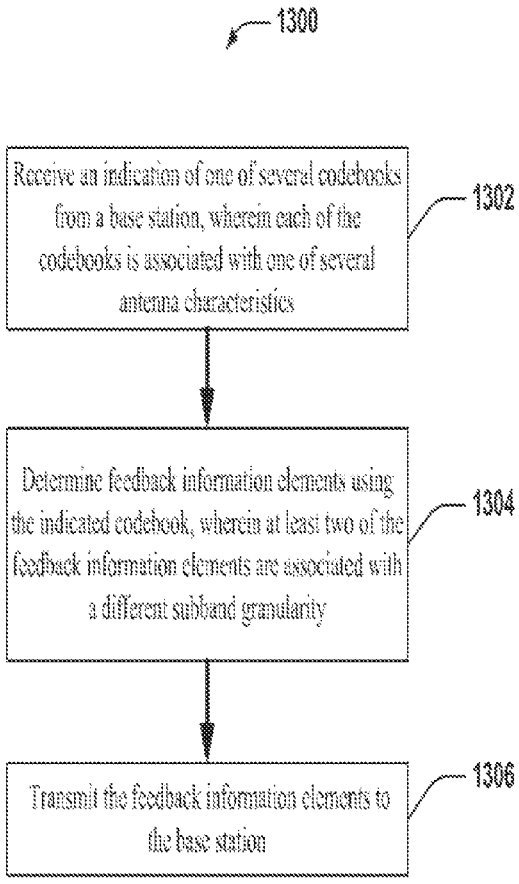

1300
Receive an indication of one of several codebooks from a base station, wherein each of the codebooks is associated with one of several antenna characteristics
1302
Determine feedback information elements using the indicated codebook, wherein at least two of the feedback information elements are associated with a different subband granularity
1304
Transmit the feedback information elements to the base station
1306

FIG. 13

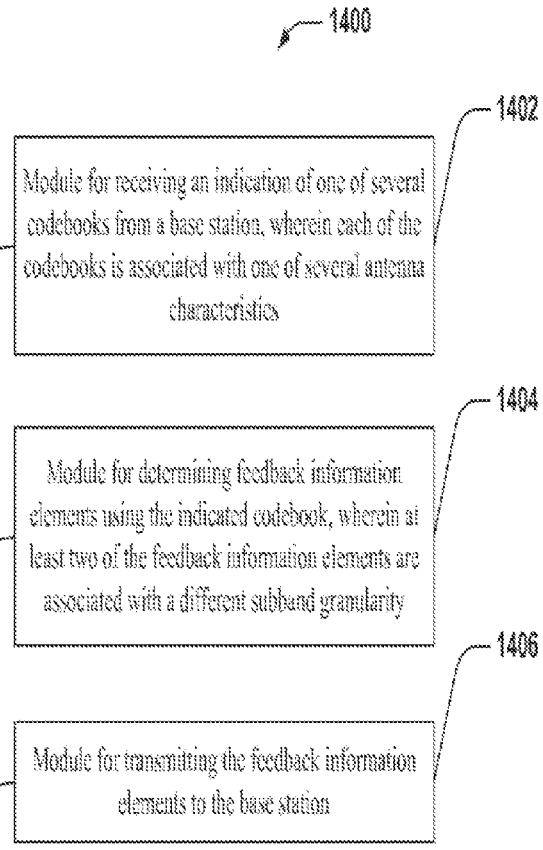

1400
Module for receiving an indication of one of several codebooks from a base station, wherein each of the codebooks is associated with one of several antenna characteristics
1402
Module for determining feedback information elements using the indicated codebook, wherein at least two of the feedback information elements are associated with a different subband granularity
1404
Module for transmitting the feedback information elements to the base station
1406

FIG. 14

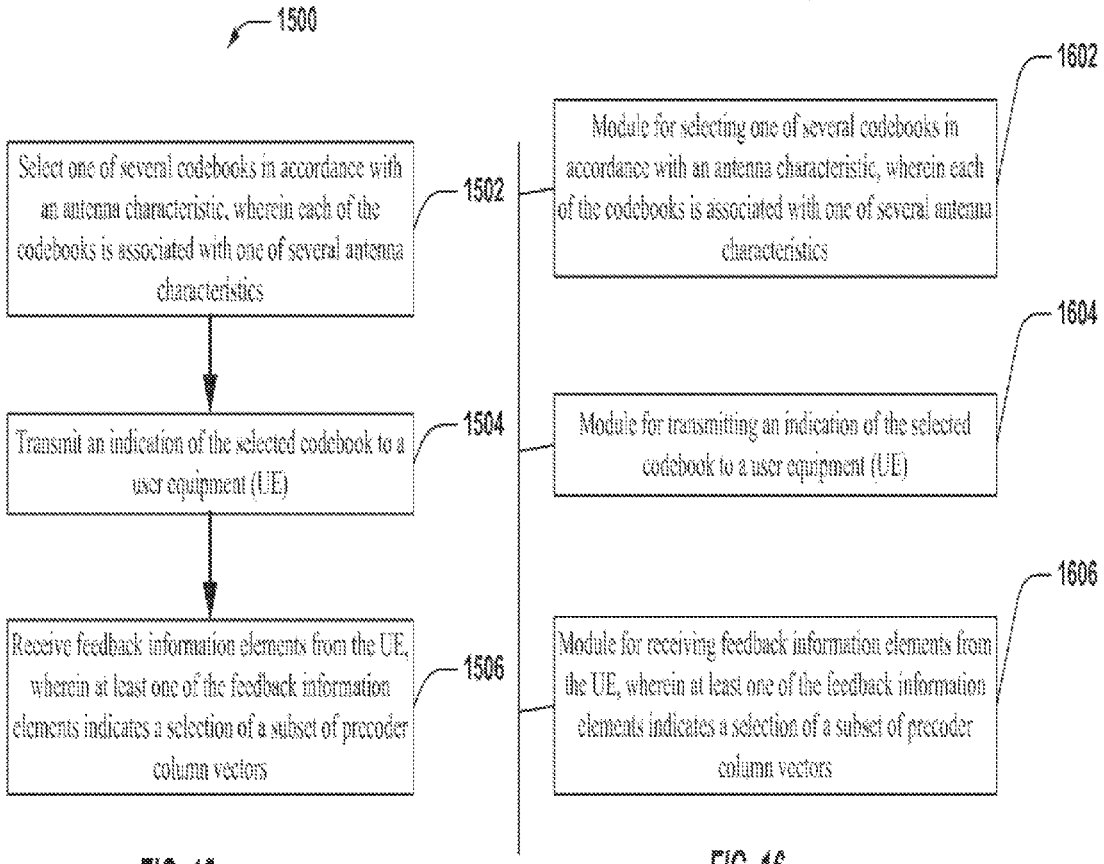

1500
Select one of several codebooks in accordance with an antenna characteristic, wherein each of the codebooks is associated with one of several antenna characteristics
1502
Transmit an indication of the selected codebook to a user equipment (UE)
1504
Receive feedback information elements from the UE, wherein at least one of the feedback information elements indicates a selection of a subset of precoder column vectors
1506
1600
Module for selecting one of several codebooks in accordance with an antenna characteristic, wherein each of the codebooks is associated with one of several antenna characteristics
1602
Module for transmitting an indication of the selected codebook to a user equipment (UE)
1604
Module for receiving feedback information elements from the UE, wherein at least one of the feedback information elements indicates a selection of a subset of precoder column vectors
1606

FIG. 15

FIG. 16

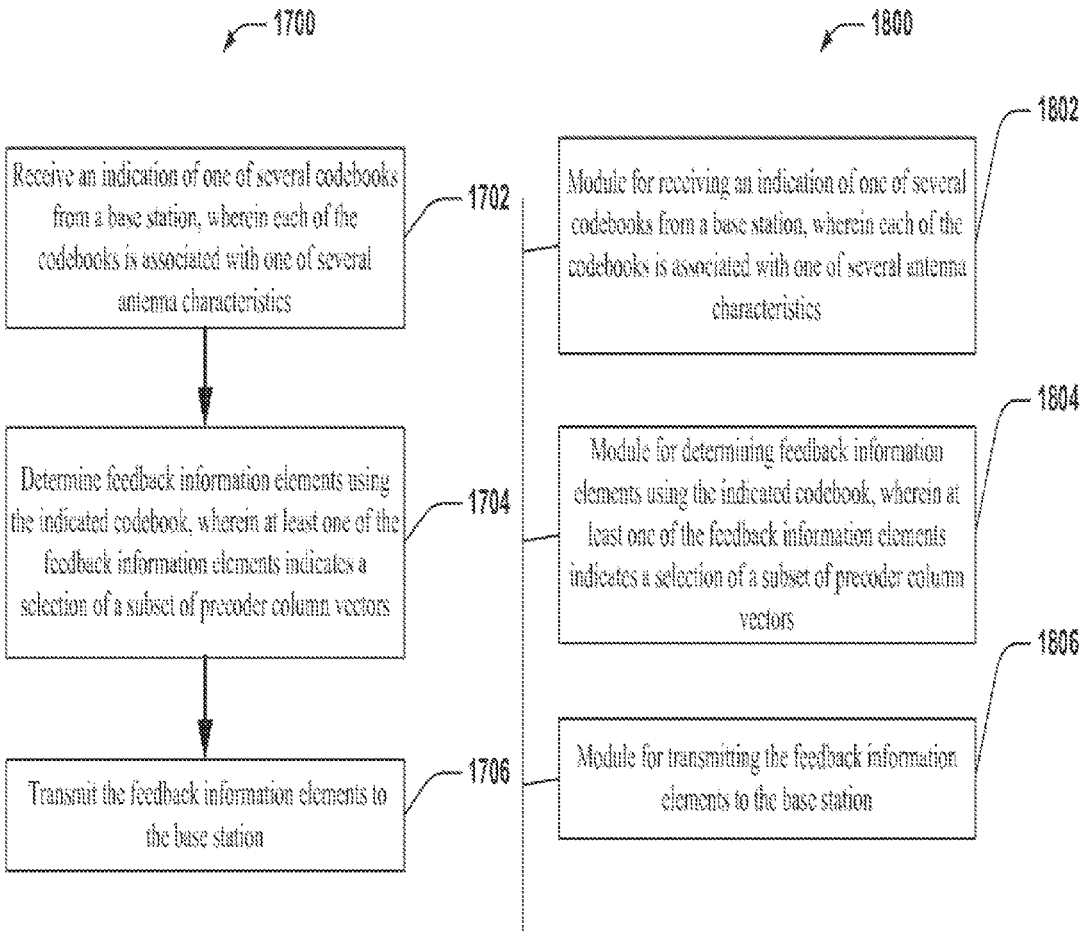

1700
Receive an indication of one of several codebooks from a base station, wherein each of the codebooks is associated with one of several antenna characteristics
1702
Determine feedback information elements using the indicated codebook, wherein at least one of the feedback information elements indicates a selection of a subset of precoder column vectors
1704
Transmit the feedback information elements to the base station
1706
1800
Module for receiving an indication of one of several codebooks from a base station, wherein each of the codebooks is associated with one of several antenna characteristics
1802
Module for determining feedback information elements using the indicated codebook, wherein at least one of the feedback information elements indicates a selection of a subset of precoder column vectors
1804
Module for transmitting the feedback information elements to the base station
1806

FIG. 17

FIG. 18

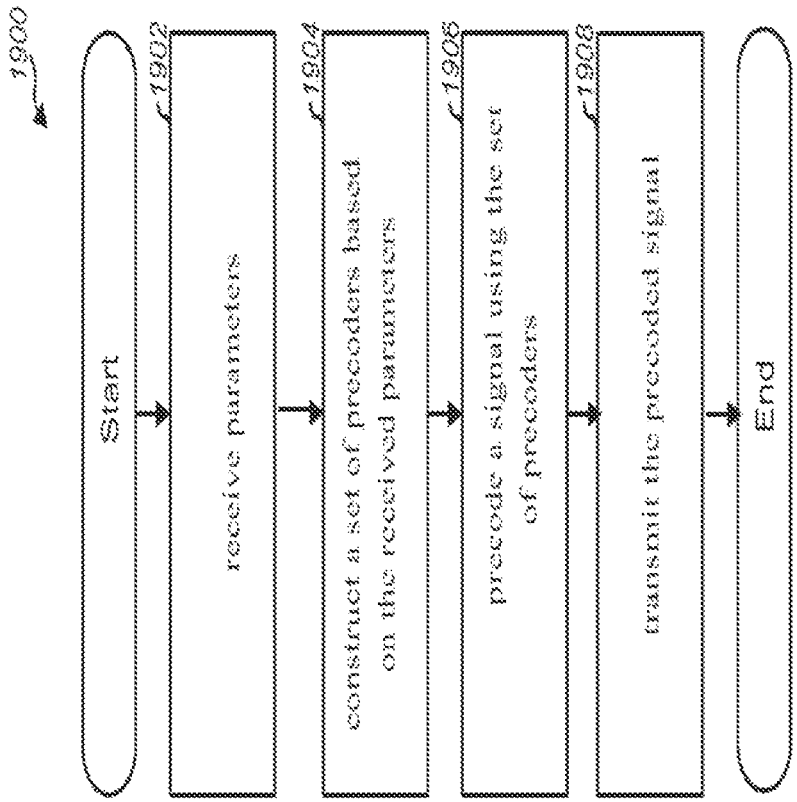

1900
Start
1902
receive parameters
1904
construct a set of precoders based on the received parameters
1906
precode a signal using the set of precoders
1908
transmit the precoded signal
End

FIG. 19

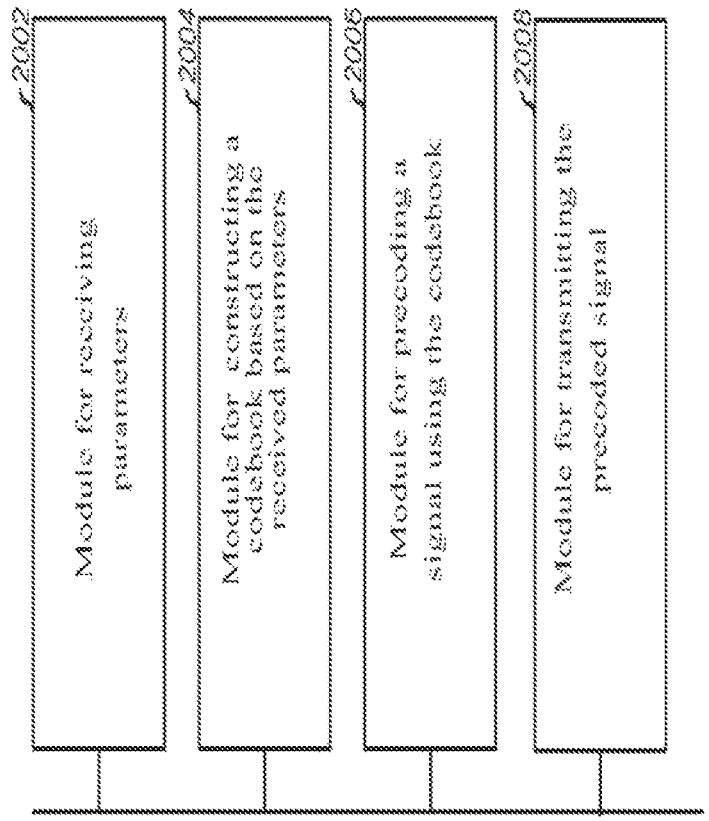

2002
Module for receiving parameters
2004
Module for constructing a codebook based on the received parameters
2006
Module for precoding a signal using the codebook
2008
Module for transmitting the precoded signal

FIG. 20

STRUCTURED MIMO CODEBOOK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 13/167,209, entitled "STRUCTURED MIMO CODEBOOK," filed on Jun. 23, 2011, now U.S. Pat. No. 8,891,652. which claims the benefit under 35 U.S.C. §119(e) to U.S. Provisional Patent Application No. 61/358,368, entitled "STRUCTURED MIMO CODEBOOK," filed on Jun. 24, 2010, the disclosures of which are expressly incorporated by reference herein in their entireties.

BACKGROUND

I. Field

The present disclosure relates generally to communication, and more specifically to techniques for generating and using codebooks in multiple-input-multiple-output (MIMO) wireless communication system.

II. Relevant Background

Wireless communication systems are widely deployed to provide various types of communication content such as voice, data, and so forth. These systems may be multiple-access systems capable of supporting communication with multiple users by sharing the available system resources (e.g., bandwidth and transmit power). Examples of such multiple-access systems include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, 3GPP Long Term Evolution (LTE) systems including E-UTRA, and orthogonal frequency division multiple access (OFDMA) systems.

An orthogonal frequency division multiplex (OFDM) communication system effectively partitions the overall system bandwidth into multiple subcarriers, which may also be referred to as frequency sub-channels, tones, or frequency bins. For an OFDM system, the data to be transmitted (i.e., the information bits) is first encoded with a particular coding scheme to generate coded bits, and the coded bits are further grouped into multi-bit symbols that are then mapped to modulation symbols. Each modulation symbol corresponds to a point in a signal constellation defined by a particular modulation scheme (e.g., M-PSK or M-QAM) used for data transmission. At each time interval that may be dependent on the bandwidth of each frequency subcarrier, a modulation symbol may be transmitted on each of the frequency subcarriers. Thus, OFDM may be used to combat inter-symbol interference (ISI) caused by frequency selective fading, which is characterized by different amounts of attenuation across the system bandwidth.

Generally, a wireless multiple-access communication system may concurrently support communication for multiple terminals that communicate with one or more base stations via transmissions on downlink and uplink. The downlink refers to the communication link from the base stations to the terminals, and the uplink refers to the communication link from the terminals to the base stations. This communication link may be established via a single-in-single-out (SISO), multiple-in-single-out (MISO) or a multiple-in-multiple-out (MIMO) system.

A MIMO system employs multiple (NT) transmit antennas and multiple (NR) receive antennas for data transmission. A MIMO channel formed by the NT transmit and NR receive antennas may be decomposed into NS independent channels, which are also referred to as spatial channels. Generally, each

of the NS independent channels corresponds to a dimension. The MIMO system may provide improved performance (e.g., higher throughput and/or greater reliability) if the additional dimensionalities created by the multiple transmit and receive antennas are utilized. A MIMO system also supports time division duplex (TDD) and frequency division duplex (FDD) systems. In a TDD system, the downlink and uplink transmissions are on the same frequency region so that the reciprocity principle allows estimation of the downlink channel from the uplink channel. This enables an access point to extract transmit beam-forming gain on the uplink when multiple antennas are available at the access point.

Development of mobile wireless broadband networks, or telecommunication networks, has been directed primarily to improving various aspects of network performance (e.g., data rates, network latency, control overhead, resource utilization . . .) within an allocated bandwidth in order to offer subscribers a better experience and ensuing perceived quality of service when utilizing applications which demand high data throughputs. In communication systems (e.g., LTE Advanced (LTE-A) Release 10), uplink (UL) spatial multiplexing of up to four layers is supported with wide-band precoding (e.g., application of a single precoding matrix per UL component carrier). In wide-band precoding, single-carrier waveform may be maintained at each antenna in a set of antennas in a user equipment (UE) and, generally, a single precoding matrix indicator (PMI) is signaled.

Advanced telecommunication networks may include a number of base stations that may support communication for a number of UEs. A base station may include multiple transmit and/or receive antennas. Each UE may include multiple transmit and/or receive antennas. For downlink (DL) transmissions, base stations may select a precoder (e.g., precoding matrix) of a codebook used for precoding the transmitted signals. The selection of codebook by a base station may depend, in part, on feedback signals received from UEs. Some systems, such as LTE Release 8 (referred to as "Rel-8" in this disclosure) may not support codebooks for greater than four transmit or receive antennas.

SUMMARY

The following presents a simplified summary of one or more embodiments in order to provide a basic understanding of such techniques and embodiments. This summary is not an extensive overview of all contemplated embodiments, and is intended to neither identify key or critical elements of all embodiments nor delineate the scope of any or all embodiments. Its sole purpose is to present some concepts of one or more embodiments in a simplified form as a prelude to the more detailed description that is presented later.

In one aspect, a method for wireless communication includes selecting a codebook from a plurality of codebooks in accordance with an antenna characteristic and transmitting an indication of the selected codebook. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics.

In another aspect, an apparatus for wireless communication includes means selecting a codebook from a plurality of codebooks in accordance with an antenna characteristic and means for transmitting an indication of the selected codebook. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics.

In yet another aspect, an apparatus for wireless communication includes at least one processor configured to select a codebook from a plurality of codebooks in accordance with an antenna characteristic and to transmit an indication of the

selected codebook. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics. The apparatus further includes a memory coupled to the at least one processor.

In yet another aspect, a computer program product including a computer-readable medium storing computer-executable instructions is disclosed. The instructions include instructions for causing at least one processor to select a codebook from a plurality of codebooks in accordance with an antenna characteristic and instructions for causing the at least one processor to transmit an indication of the selected codebook. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics.

In yet another aspect, a method for wireless communication includes receiving an indication of a codebook of a plurality of codebooks, determining channel state information feedback using the codebook of the plurality of codebooks, and transmitting the channel state information feedback. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics.

In yet another aspect, an apparatus for wireless communication includes means for receiving an indication of a codebook of a plurality of codebooks, means for determining channel state information feedback using the codebook of the plurality of codebook, and means for transmitting the channel state information feedback. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics.

In yet another aspect, an apparatus for wireless communication includes at least one processor configured to receive an indication of a codebook of a plurality of codebooks, to determine channel state information feedback using the codebook of the plurality of codebooks, and to transmit the channel state information feedback. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics. The apparatus further includes a memory coupled to the at least one processor.

In yet another aspect, a computer program product including a non-transitory computer-readable medium storing computer-executable instructions is disclosed. The instructions include instructions for causing at least one processor to receive an indication of a codebook of a plurality of codebooks, instructions for causing the at least one processor to determine channel state information feedback using the codebook of the plurality of codebooks, and instructions for causing the at least one processor to transmit the channel state information feedback. Each of the plurality of codebooks is associated with one of a plurality of antenna characteristics.

In yet another aspect, a method for wireless communication includes receiving a plurality of channel phase feedback information elements from a user equipment. At least two of the plurality of channel phase feedback information elements are associated with a different subband granularity.

In yet another aspect, an apparatus for wireless communication includes means for receiving a plurality of channel phase feedback information elements from a user equipment. At least two of the plurality of channel phase feedback information elements are associated with a different subband granularity

In yet another aspect, a method for wireless communication includes determining a plurality of channel phase feedback information elements using a codebook of the plurality of codebooks and transmitting the plurality of channel phase feedback information elements to a base station. At least two of the plurality of channel phase feedback information elements are associated with a different subband granularity.

In yet another aspect, an apparatus for wireless communication includes means for determining a plurality of channel phase feedback information elements using a codebook of the plurality of codebooks and means for transmitting the plurality of channel phase feedback information elements to a base station. At least two of the plurality of channel phase feedback information elements are associated with a different subband granularity.

In yet another aspect, a method for wireless communication includes receiving a plurality of feedback information elements from a user equipment. At least one of the plurality of feedback information elements indicates a selection of a subset of precoder column vectors.

In yet another aspect, an apparatus for wireless communication includes means for receiving a plurality of feedback information elements from a user equipment. At least one of the plurality of feedback information elements indicates a selection of a subset of precoder column vectors.

In yet another aspect, a method for wireless communication includes receiving an indication of a codebook of a plurality of codebooks from a base station, wherein each of the plurality of codebooks is associated with one of a plurality of antenna characteristics, determining a plurality of feedback information elements using the codebook of the plurality of codebooks, wherein at least one of the plurality of feedback information elements indicates a selection of a subset of precoder column vectors, and transmitting the plurality of feedback information elements to the base station.

In yet another aspect, an apparatus for wireless communication includes means for receiving an indication of a codebook of a plurality of codebooks from a base station, wherein each of the plurality of codebooks is associated with one of a plurality of antenna characteristics, means for determining a plurality of feedback information elements using the codebook of the plurality of codebooks, wherein at least one of the plurality of feedback information elements indicates a selection of a subset of precoder column vectors, and means for transmitting the plurality of feedback information elements to the base station.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, nature, and advantages of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. **1** illustrates a multiple access wireless communication system according to one embodiment.

FIG. **2** illustrates a block diagram of a communication system.

FIG. **3** illustrates a diagram of a communication system.

FIGS. **4**A-F illustrate exemplary transmit antenna configurations, in accordance with certain configurations disclosed in the present disclosure.

FIG. **5** is a flow chart representation of a process for wireless communication.

FIG. **6** is a block diagram representation of a portion of a wireless communication apparatus.

FIG. **7** illustrates an exemplary coupling of electrical components that facilitates implementing a structured codebook.

FIG. **8** is a flow chart representation of a process for wireless communication.

FIG. **9** is a block diagram representation of a portion of a wireless communication apparatus.

FIG. **10** illustrates an exemplary coupling of electrical components that facilitates implementing a structured codebook.

FIG. **11** is a flow chart representation of a process for wireless communication.

FIG. **12** is a block diagram representation of a portion of a wireless communication apparatus.

FIG. **13** is a flow chart representation of a process for wireless communication.

FIG. **14** is a block diagram representation of a portion of a wireless communication apparatus.

FIG. **15** is a flow chart representation of a process for wireless communication.

FIG. **16** is a block diagram representation of a portion of a wireless communication apparatus.

FIG. **17** is a flow chart representation of a process for wireless communication.

FIG. **18** is a block diagram representation of a portion of a wireless communication apparatus.

FIG. **19** is a flow chart representation of a process for wireless communication.

FIG. **20** is a block diagram representation of a portion of a wireless communication apparatus.

DESCRIPTION

Various aspects are now described with reference to the drawings. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects. It may be evident, however, that the various aspects may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing these aspects.

The techniques described herein may be used for various wireless communication networks such as CDMA networks, TDMA networks, FDMA networks, OFDMA networks, Single-Carrier FDMA (SC-FDMA) networks, etc. The terms "networks" and "systems" are often used interchangeably. A CDMA network may implement a radio technology such as Universal Terrestrial Radio Access (UTRA), cdma2000, etc. UTRA includes Wideband-CDMA (W-CDMA) and Low Chip Rate (LCR). cdma2000 covers IS-2000, IS-95 and IS-856 standards. A TDMA network may implement a radio technology such as Global System for Mobile Communications (GSM). An OFDMA network may implement a radio technology such as Evolved UTRA (E-UTRA), IEEE 802.11, IEEE 802.16, IEEE 802.20, Flash-OFDM®, etc. UTRA, E-UTRA, and GSM are part of Universal Mobile Telecommunication System (UMTS). LTE is a release of UMTS that uses E-UTRA. UTRA, E-UTRA, GSM, UMTS and LTE are described in documents from an organization named "3rd Generation Partnership Project" (3GPP). cdma2000 is described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). For clarity, certain aspects of the techniques are described below for LTE, and LTE terminology is used in much of the description below. However, the various aspects described herein may be implemented in most any or any telecommunication network, and associated radio technology protocols.

SC-FDMA utilizes single carrier modulation and frequency domain equalization. SC-FDMA signal has lower peak-to-average power ratio (PAPR) because of its inherent single carrier structure. SC-FDMA has drawn great attention, especially in the uplink communications where lower PAPR greatly benefits the mobile terminal in terms of transmit power efficiency. It is currently used for uplink multiple access scheme in LTE, or Evolved UTRA. There may also be other waveforms with low PAPR, such as clustered SC-FDMA signals, CDMA signals with certain code channel configurations, OFDMA signals after applying certain PAPR reduction techniques, or generally any low PAPR signal. For illustrative purposes the systems and methods described herein reference SC-FDMA signals, however the systems and methods apply equally to any other low PAPR signals.

One of the enhancements considered for DL in LTE Release 10 was the support for eight transmit antennas and eight receive antennas (8×8) for single user MIMO (SU-MIMO) and multi-user MIMO (MU-MIMO). The structured codebook schemes disclosed in the present disclosure may be used in the Release 10 specification, or any subsequent specification or similar systems. In certain configurations, the structured codebooks may exhibit the following properties: (1) use and support 8-PSK alphabet, (2) codebook entries having constant modulus, and (3) nested structure. In certain configurations, one or more (but not all) of the listed properties may be satisfied by the disclosed codebooks. In some situations one or more of the properties may be relaxed if there is a demonstrable benefit better systems performance by doing so.

In a communication system comprising eight transmit antennas, several transmit antenna configurations for DL transmission are possible, for example, eight uniform linear array (ULA) antennas, four ULA antennas, eight cross-polarized (x-pol) antennas, and so on. In certain aspects, the structured codebook representations disclosed in the present disclosure provide for a parameterized description of codebooks, which is responsive to a configuration of transmit antennas. A transmitter (e.g., a base station) may be able to optimize transmission for various transmit antenna configurations by simply adjusting or choosing values of the parameters. Furthermore, a base station may assign a different number of subcarriers, or resource blocks (RBs), to different parameters of the structured codebook for signaling in the uplink direction by a UE. The base station may indicate the subcarrier assignment to the UE in a downlink message.

FIG. **1** shows an exemplary wireless communication system **100**, which may be an LTE system or some other system. The exemplary system **100** may utilize a structured codebook, such as in accordance with aspects described herein. System **100** may include a number of evolved Node Bs (eNBs) **110** and other network entities. An eNB may be an entity that communicates with the UEs and may also be referred to as a base station, a Node B, an access point, etc. Each eNB **110** may provide communication coverage for a particular geographic area and may support communication for the UEs located within the coverage area. To improve capacity, the overall coverage area of an eNB may be partitioned into multiple (e.g., three) smaller areas. Each smaller area may be served by a respective eNB subsystem. In 3GPP, the term "cell" may refer to the smallest coverage area of an eNB **110** and/or an eNB subsystem serving this coverage area.

UEs **120** may be dispersed throughout the system, and each UE **120** may be stationary or mobile. A UE may also be referred to as a mobile station, mobile device, a terminal, an access terminal, a subscriber unit, etc. A UE **120** may be a cellular phone, a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a laptop computer, a cordless phone, a wireless local loop (WLL) station, a smart phone, a netbook, a smartbook, a tablet, etc.

LTE utilizes OFDM on the downlink and SC-FDM on the uplink. OFDM and SC-FDM partition a frequency range into

multiple (K_s) orthogonal subcarriers, which are also commonly referred to as tones, bins, etc. Each subcarrier may be modulated with data. In general, modulation symbols are sent in the frequency domain with OFDM and in the time domain with SC-FDM. The spacing between adjacent subcarriers may be fixed, and the total number of subcarriers (K_s) may be dependent on the system bandwidth. For example, K_s may be equal to 128, 256, 512, 1024 or 2048 for system bandwidth of 1.4, 3, 5, 10 or 20 MHz, respectively. The system bandwidth may correspond to a subset of the K_s total subcarriers.

FIG. **2** shows a block diagram of an exemplary base station **110** and UE **120**, which may be one of the eNBs and one of the UEs in FIG. **1**. The UE **120** may be equipped with T antennas **234***a* through **234***t*, and the base station **110** may be equipped with R antennas **252***a* through **252***r*, where in general T≥1 and R≥1.

At UE **120**, a transmit processor **220** may receive data from a data source **212** and control information from a controller/processor **240**. Transmit processor **220** may process (e.g., encode, interleave, and symbol map) the data and control information and may provide data symbols and control symbols, respectively. Transmit processor **220** may also generate one or more demodulation reference signals for multiple non-contiguous clusters based on one or more RS sequences assigned to UE **120** and may provide reference symbols. A transmit (TX) MIMO processor **230** may perform spatial processing (e.g., precoding) on the data symbols, the control symbols, and/or the reference symbols from transmit processor **220**, if applicable, and may provide T output symbol streams to T modulators (MODs) **232***a* through **232***t*. Each modulator **232** may process a respective output symbol stream (e.g., for SC-FDMA, OFDM, etc.) to obtain an output sample stream. Each modulator **232** may further process (e.g., convert to analog, amplify, filter, and upconvert) the output sample stream to obtain an uplink signal. T uplink signals from modulators **232***a* through **232***t* may be transmitted via T antennas **234***a* through **234***t*, respectively.

At base station **110**, antennas **252***a* through **252***r* may receive the uplink signals from UE **120** and provide received signals to demodulators (DEMODs) **254***a* through **254***r*, respectively. Each demodulator **254** may condition (e.g., filter, amplify, downconvert, and digitize) a respective received signal to obtain received samples. Each demodulator **254** may further process the received samples to obtain received symbols. A channel processor/MIMO detector **256** may obtain received symbols from all R demodulators **254***a* through **254***r*. Channel processor **256** may derive a channel estimate for a wireless channel from UE **120** to base station **110** based on the demodulation reference signals received from UE **120**. MIMO detector **256** may perform MIMO detection/demodulation on the received symbols based on the channel estimate and may provide detected symbols. A receive processor **258** may process (e.g., symbol demap, deinterleave, and decode) the detected symbols, provide decoded data to a data sink **260**, and provide decoded control information to a controller/processor **280**.

On the downlink, at base station **110**, data from a data source **262** and control information from controller/processor **280** may be processed by a transmit processor **264**, precoded by a TX MIMO processor **266** if applicable, conditioned by modulators **254***a* through **254***r*, and transmitted to UE **120**. At UE **120**, the downlink signals from base station **110** may be received by antennas **234**, conditioned by demodulators **232**, processed by a channel estimator/MIMO detector **236**, and further processed by a receive processor **238** to obtain the data and control information sent to UE **120**. Processor **238** may provide the decoded data to a data sink **239** and the decoded control information to controller/processor **240**.

Controllers/processors **240** and **280** may direct the operation at UE **120** and base station **110**, respectively. Processor **220**, processor **240**, and/or other processors and modules at UE **120** may perform or direct process **800** of FIG. **8**, process **1300** of FIG. **13**, process **1700** of FIG. **17**, and/or other processes for the techniques described herein. Processor **256**, processor **280**, and/or other processors and modules at base station **110** may perform or direct process **500** of FIG. **5**, process **1100** of FIG. **11**, process **1500** of FIG. **15**, process **1900** of FIG. **19**, and/or other processes for the techniques described herein. Memories **242** and **282** may store data and program codes for UE **120** and base station **110**, respectively. A scheduler **284** may schedule UEs for downlink and/or uplink transmission and may provide allocations of resources (e.g., assignment of multiple non-contiguous clusters, RS sequences for demodulation reference signals, etc.) for the scheduled UEs.

Advances in digital communication have led to the use of multiple transmission antennas on UE **120**. For example, in LTE Release 10, an SU-MIMO mode is defined, in which, a UE **120** may transmit up to two transport blocks (TBs) to the base station **110**. TBs are also sometimes called codewords (CWs), although sometimes the mapping from TBs to CWs may follow a permutation, such as swapping two TBs mapped to a pair of CWs.

FIG. **3** shows a block diagram of an exemplary system **300** that may implement a structured codebook, such as in accordance with various aspects of the subject disclosure. In system **300**, an exemplary base station **110** and exemplary UE **120**, may be one of the eNBs and one of the UEs in FIGS. **1-2**, or in other MIMO systems implementing a structured codebook, such as in accordance with aspects described herein

UE **120** may include a feedback determination component **304**, one or more processor(s) **308**, a radio component **312**, and memory **324**. Feedback determination component **304** may determine feedback information elements using a codebook indicated by the base stations **110** in accordance with aspects described herein. Base station **110** may include a radio component **340**, a configuration component **348**, a processor **350**, and memory **352**. UE **120** may communicate (e.g., exchange data and signaling) with base station **110** through wireless uplink and downlink via the radio component **312**.

In an aspect, UE **120** includes a memory **324** which may be a computer-readable storage medium, such as a non-transitory computer-readable medium, that retains code instructions that, when executed by processor(s) **308**, implement the functionality in connection with receiving an indication of a codebook from the base station **110**, determine feedback information using the indicated codebook, and transmit the feedback information to the base station **110** according to aspects described in the subject disclosure. It should be appreciated that in one or more embodiments, feedback determination component **304** and at least a portion of radio component **312** may reside within memory **324** as one or more sets of code instructions; in such one or more embodiments, functionality of feedback determination component **304** or at least the portion of radio component **312** may be implemented when processor(s) **308** execute the one or more set of code instructions. In additional or alternative embodiments, processor(s) **308** may be distributed as part of feedback determination component **304**, or component(s) therein, or radio component **312**, or component(s) therein. It should be appreciated that the various components that are part of UE **120**

may exchange data via several communication protocols and related architecture, such as a bus architecture.

In another aspect, base station **110** includes a memory **352** which may be a computer-readable storage medium, such as a non-transitory computer-readable medium, that retains code instructions that, when executed by processor(s) **350**, implement the functionality in connection with the structured codebook disclosed herein. It should be appreciated that in one or more embodiments, configuration component **348** and at least a portion of radio component **340** may reside within memory **352** as one or more sets of code instructions; in such one or more embodiments, functionality of configuration component **348** or at least the portion of radio component **340** is implemented when processor(s) **350** execute the one or more set of code instructions. In additional or alternative embodiments, processor(s) **350** may be distributed as part of configuration component **348**, or component(s) therein, or radio component **340**, or component(s) therein. It should be appreciated that the various components that are part of base station **110** may exchange data via several communication protocols and related architecture, such as a bus architecture.

FIGS. **4**A-F are diagrammatic representations of various transmit antenna configurations, in accordance with configurations disclosed in the present disclosure.

FIG. **4**A may represent a transmit antenna configuration **400** in which all eight antennas are phase aligned and closely spaced.

FIG. **4**B may represent a transmit antenna configuration **402** comprising two antenna groups, spaced apart from each other, all antennas (e.g., all four antennas) within a group closely spaced and aligned with respect to each other.

FIG. **4**C may represent a transmit antenna configuration **404** comprising two antenna groups; a first group of four closely spaced and aligned antennas, having cross-polarization with respect to a second group of four closely spaced and aligned antennas.

FIG. **4**D may represent a transmit antenna configurations **406** in which antennas are arranged as four pairs of aligned antennas, with two closely spaced antennas forming a pair.

FIG. **4**E may represent a transmit antenna configurations **408** in which antennas are arranged as four pairs of antennas, with each pair having two closely spaced, cross-polarized antennas, and each of the four pairs being spaced apart from each other.

FIG. **4**F may represent a transmit antenna configuration **410** in which antennas are arranged as four antenna pairs, spaced apart from each other, with antennas in each pair closely spaced and cross-polarized with respect to each other.

It may be desirable to select different codebooks based on one or more transmit antenna characteristics, such as the different antenna configurations illustrated in FIGS. **4**A-F. It may be desirable for such a codebook to have the following properties: (1) 8-PSK alphabet, (2) Constant modulus, and (3) Nested structure. However, one or more of these properties may be relaxed if there is a demonstrable benefit resulting in better systems performance. In general, a precoder may be a unitary matrix and a codebook may be a set of unitary transformations. Example transformation operations that preserve the unitary property may include:

O1. Permuting columns

O2. Multiplying columns with a unit norm complex scalar

O3. Permuting rows

O4. Multiplying rows with a unit norm complex scalar

O5. Left or right multiply with a unitary matrix

However, operation (O5) may not strictly preserve constant modulus properties, and therefore may not be desirable for designing a codebook in some cases. In general, the operation (O2) above may be transparent when the matrix is used as a precoder. Operation (O1) may have an impact when the precoder is not full rank and the other transformations may in general change the coefficient values of a precoder.

In certain configurations, operations (O4) and (O1) above may be used as a part of a codebook design. In other words, starting from a base unitary matrix, precoders of a structured codebook may be obtained by multiplying rows by scalars primarily, and by permuting the columns in the non full rank cases.

With the use of demodulation reference signals (DM-RS), the nested structure property may not be as important, but may still be useful in enabling better MU-MIMO multiplexing for UEs reporting different ranks.

The Householder transformation used in certain codebooks (e.g., Rel-8) may not be extendable to 8 antennas without violating the constant modulus properties. In certain configurations according to the present disclosure, by transforming the Householder precoders by multiplying columns with a constant (which is completely transparent when the matrix is considered as a precoder) certain codebook design principle may be extendible to 8 antennas.

The 4×4 Rel-8 codebook is derived by using the Householder transformation, which generates an orthogonal matrix from an input 4×1 column vector u_n by applying:

$$W_n = I - 2u_n u_n^H / u_n^H u_n \tag{1}$$

Considering W_n as a precoder, columns may be multiplied with a unit norm constant scalar. W_n may be transformed to $\tilde{W}_n$ by multiplying each columns with the elements of u_n:

$$\tilde{W}_n = W_n \cdot \mathrm{diag}(u_n) \tag{2}$$

where

$$\mathrm{diag}(u_n) = \begin{bmatrix} u_1 & 0 & 0 & 0 \\ 0 & u_2 & 0 & 0 \\ 0 & 0 & u_3 & 0 \\ 0 & 0 & 0 & u_4 \end{bmatrix} \tag{3}$$

The result may be expressed as:

$$\tilde{W}_n = (I - 2u_n u_n^H / u_n^H u_n) \cdot \mathrm{diag}(u_n) = \mathrm{diag}(u_n) \cdot Q_{4\times4} \tag{4}$$

where

$$Q_{4\times4} = \frac{1}{2} \cdot \begin{bmatrix} -1 & +1 & +1 & +1 \\ +1 & -1 & +1 & +1 \\ +1 & +1 & -1 & +1 \\ +1 & +1 & +1 & -1 \end{bmatrix} \tag{5}$$

Therefore, in Rel-8, all 4×4 precoders are derivable by taking a 4×1 column vector u_n and right multiplying it with the same orthonormal matrix $Q_{4\times4}$. Note that $Q_{4\times4}$ itself is a transformation of the 4×4 Hadamard matrix by using operations (O1), (O2) and (O4) discussed above. In addition, column permutation was defined for the Rel-8 codebook for some rank **2**, **3** precoders. This is specified as particular column selections for those cases in Rel-8.

In certain configurations disclosed in the present disclosure, similar design principles may be extended in constructing 8×8 codebooks. For clarity, the structured codebook construction is explained with respect to a rank **1** precoder. It is understood that a full rank precoder may be derived by simply right multiplying the rank **1** precoder with an orthonormal matrix.

According to certain configurations disclosed in the present disclosure, a codebook may be constructed as follows:

Define a set of u_n rank **1** precoders where each u_n is a 8×1 column vector. Each vector u_n may have a dual codebook structure. Each precoder W_n in the codebook may be derived as:

$$W_n=\mathrm{diag}(u_n)\cdot Q_{8\times 8} \tag{6}$$

where $Q_{8\times 8}$ is a 8×8 Hadamard matrix after a bit-reversed column permutation:

$$Q_{8\times 8}=\frac{1}{2\cdot\sqrt{2}}\cdot\begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ +1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \\ +1 & +1 & -1 & -1 & -1 & -1 & +1 & +1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & -1 & +1 & -1 & -1 & +1 & -1 & +1 \\ +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 \\ +1 & -1 & -1 & +1 & -1 & +1 & +1 & -1 \end{bmatrix} \tag{7}$$

In addition, for certain antenna configurations, and for some rank cases, column permutations of the precoders may be considered, similar to the permutations performed in the Rel-8 codebook.

A number of transmit antenna configurations may be used at a base station (or eNB), such as the antenna configurations described in FIGS. **4**A-F. The structured codebook disclosed herein allows adaptability by parameterizing a codebook and allowing selection of a codebook based on the transmit antenna configuration.

In certain configurations, each precoder is derived from a u_n basis vector. The UE feedback may point to one of the u_n basis vectors, and possibly to a column permutation. The latter may primarily target optimizing rank **2** feedback.

The vector u_n may be expressed as a formula where the elements of u_n are calculated based on discrete feedback components. However, it is understood that the set $\{u_n\}$ may be viewed just as a simple enumeration of a set of chosen vectors

In certain configurations, the set $u_n=[u_{n,0}, u_{n,1}, u_{n,2}, \ldots, y_{n,7}]^T$ may be expressed as:

$$u_n=f(a_0,b_0,c_0,c_1,d_1,d_2,d_3) \tag{8}$$

i.e. as a function of a number of discrete parameters such that

$$u_{n,k}=\exp(2\pi j\cdot(a_0\cdot k+b_0\cdot\lfloor(k+4)/8\rfloor+c_0\cdot\lfloor(k+6)/8\rfloor+c_1\cdot\lfloor(k+2)/8\rfloor+d_1\cdot\lfloor(k+5)/8\rfloor+d_2\cdot\lfloor(k+3)/8\rfloor+d_3\cdot\lfloor(k+1)/8\rfloor)) \tag{9}$$

Note that not all parameters need to be used in deriving a codebook. For example, parameters that are not used may be set to zero in Eq. (9).

The parameters (a_0, b_0, c_0, c_1, d_1, d_2, d_3) may relate to transmit antenna configurations. For example. a_0 may correspond to a rank **1** precoder and may represent the case when all antennas in the transmit antenna configuration are closely located and are in phase. For feedback of the parameter a_0, a greater number of subband RBs may be assigned because frequency variability will be less when the transmit antenna configuration corresponds to in phase, closely located antennas.

As another example, parameters d_1, d_2, d_3 may be more correlated than b_0, for example, therefore d_1, d_2, d_3 may have lower subband granularity than b_0. In other words, a greater number of subband resource blocks may be assigned to d_1, d_2, d_3 for feedback by a UE, compared to that for b_0.

In certain configurations, signaling is selected from the four basic configurations listed in Table 1 below.

TABLE 1

Feedback Configuration Cases

Configuration number	Tx antenna configurations covered	Wideband feedback parameter set	Subband feedback parameter set	Column permutation set
1	FIG. 4A	a_0	a_0, b_0, c_0, c_1, d_1, d_2, d_3	N/A
2	FIG. 4B, FIG. 4C	a_0, b_0	a_0, b_0, c_0, c_1, d_1, d_2, d_3	N/A
3	FIG. 4D, FIG. 4E	a_0, b_0, c_0, c_1	a_0, b_0, c_0, c_1, d_1, d_2, d_3	{[1 2 3 4 5 6 7 8], [1 3 4 2 5 6 7 8], [1 4 2 3 5 6 7 8]}
4	FIG. 4F	a_0, b_0, c_0, c_1, d_1, d_2, d_3	a_0, b_0, c_0, c_1, d_1, d_2, d_3	{[1 2 3 4 5 6 7 8], [1 3 4 2 5 6 7 8], [1 4 2 3 5 6 7 8]}

The signaling for configuration selection could be cell-specific although if more flexibility in feedback configuration is desired, UE-specific signaling could be considered. In Table 1 above, four example transmit antenna configurations, corresponding to four rows in Table 1, are shown. As discussed previously, wideband parameter set for the transmit antenna configuration **400** of FIG. **4**A comprises a_0. For the transmit antenna configurations **402** and **404** of FIGS. **4**B and **4**C, respectively, an additional parameter b_0 may be added, for example, corresponding to the additional feature that antennas are grouped either with different phases or are spaced apart in two groups. Similarly, additional parameters c_0, c_1, d_1, d_2, and d_3 for representing additional transmit antenna configuration details depicted in configurations **406**, **408** and **410** of FIGS. **4**D, **4**E, and **4**F, respectively.

In certain configurations, the set of parameters, the bit resolution used for each parameter, and the subcarrier resource blocks assigned for feedback of each parameter from a UE to a base station/eNB, may be determined based on the number of transmit antenna configurations supported. Two illustrative examples are given below in Tables 2 and 3.

TABLE 2

Feedback Configuration for 8 Tx ULA

Tx antenna configuration	Feedback parameter	Values	Number of bits	Subband size (RBs)
FIG. 4A	a_0	{0, 1/8, 2/8, . . . , 7/8}	3	50
	b_0	{0, 1/8}	1	6
	c_0	{0, 1/8}	1	12
	c_1	{0, 1/8}	1	12
	d_1	{0, 1/8}	1	24
	d_2	{0, 1/8}	1	24
	d_3	{0, 1/8}	1	24

Table 2 above relates to the antenna configuration **400** depicted in FIG. **4**A, and Table 3 below relates to the antenna configuration **410** depicted in FIG. **4**F. The second column may show the feedback parameters used to characterize and/or construct codebooks. The third column may show the values that may be assigned to each parameter. The fourth column may list a number of bits required to signal value of the parameter in a feedback message from a UE to a base station. The last column may list the number of subbands or resource blocks (RBs) over which a given parameter is

assumed to be constant. For example, parameter a_0 may represent aligned set of closely spaced antennas, and therefore may not vary over a frequency band. Therefore, a_0 is assumed to be unchanging over a subband size of 50 RBs (e.g., the entire 10 MHz bandwidth). In certain configurations, the size of subbands allocated to a parameter may be a multiple of 6 RBs, to be consistent with the Rel-8 RB assignment.

Still referring to Tables 2 and 3, parameter b_0 may be associated with cross-polarized (e.g., as depicted in FIG. **4**C). Therefore, to mitigate possible spectral variations, the feedback channel for b_0 may be assigned a smaller number of RBs (e.g., six). Likewise, a different number of RBs may be assigned to c_0, c_1 (exhibiting larger frequency variations due to cross polarization and farther spacing of antennas) and d_1, d_2, and d_3 (exhibiting less frequency variation than c_0, c_1 due to nearer spacing of antennas). In certain configurations, when a parameter is assigned fewer number of RBs, to cover the entire bandwidth of the DL channel, a greater number of parameter updates may have to be signaled on the feedback channel from a UE to a base station.

TABLE 3

Feedback Configuration for 8 Tx x-pol

Tx antenna configuration	Feedback parameter	Values	Number of bits	Subband size (RBs)
FIG. 4F	a_0	{0, 1/8, 2/8, . . . , 7/8}	3	50
	b_0	Rank 1: {0, 1/4, 1/2, 3/4} Rank 2: {0, 1/4}	Rank 1: 2 Rank 2: 1	6
	c_0	{0, 1/8}	1	12
	c_1	{0, 1/8}	1	12
	d_1	Rank 1: {0} Rank 2: {0, 1/8}	Rank 1: 0 Rank 2: 1	24
	d_2	Rank 1: {0} Rank 2: {0, 1/8}	Rank 1: 0 Rank 2: 1	24
	d_3	Rank 1: {0} Rank 2: {0, 1/8}	Rank 1: 0 Rank 2: 1	24

Other configurations may also be possible. For example, higher feedback granularity on the feedback channel may give better DL spectral efficiency vs. UL feedback overhead trade off Referring to Tables 2 and 3, as an example, in a wireless system with 10 MHz downlink bandwidth, a subband size of 50 RBs may correspond to the entire DL bandwidth. Therefore, the entry a_0 may have to be sent on the feedback channel just once for the entire bandwidth. On the other hand, b_0 is assigned **6** subband RBs, requiring a UE to send nine different values of b_0 to span the entire 50 RB bandwidth of the 10 MHz channel.

FIG. **5** is a flow chart representation of a wireless communication methodology **500**. At box **502**, a codebook is selected from several codebooks in accordance with an antenna characteristic, such as a transmit antenna configuration. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F.

At box **504**, an indication of the selected codebook is transmitted, such as to a UE **120**. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, all of the codebooks may be known to a UE **120**, such as stored locally at the UE **120**, and a base station **110** may only need to signal an indication of the selected codebook, rather than the entire selected codebook. The methodology **500** may further include receiving channel state information feedback from the UE **120** and determining downlink scheduling and/or precoding based on the channel state information feedback. The channel state information feedback may include feedback information elements, such as the wideband and/or subband feedback parameters discussed above and shown in Tables 1-3. In one example, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. For example, at least two of the feedback information elements, such as the wideband and/or subband feedback parameters, may be assigned a different number of resource blocks (RBs), as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. For example, at least one of the feedback information elements may include a column permutation set, such as one of the column permutation sets shown in Table 1. The base station **110** may use the indicated subset of precoder column vectors to determine one or more precoders for precoding a signal. Alternatively, or in addition, at least one of the feedback information elements may include a channel phase feedback information element that indicates a phase offset between two groups of transmit antennas, such as the feedback parameter b_0 discussed above. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements. Alternatively or in addition, the channel phase feedback information element may include other information related to the channel phase.

FIG. **6** is a block diagram representation of a portion of a wireless communication apparatus **600**. Module **602** is provided for selecting a codebook from several codebooks in accordance with an antenna characteristic, such as a transmit antenna configuration. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. Module **604** is provided for transmitting an indication of the selected codebook, such as to a UE **120**. In one example, the indication of the selected codebook may include less information than the codebook itself

FIG. **7** is a block diagram of a system **700** that facilitates implementing a structured codebook, according to an embodiment. System **700** includes functional blocks that may represent functions implemented by a processor, software, or combination thereof (e.g., firmware), wherein system **700** includes a logical grouping **702** of electrical components that may act in conjunction. As illustrated, logical grouping **702** may include an electrical component for selecting a codebook from several codebooks in accordance with an antenna characteristic **710**, such as a transmit antenna configuration, as well as an electrical component for transmitting an indication of the selected codebook **712**, such as to a UE **120**. For example, each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F, and the indication of the codebook may include less information than the codebook itself. In another aspect, channel state information feedback may be received from the UE **120**, and downlink scheduling and/or precoding may be determined based on the channel state information feedback. The channel state information feedback may include feedback information elements. In one example, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Alternatively, or in addition, at least one of the feedback informa-

tion elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements. Additionally, system **700** may include a memory **720**, such as a non-transitory computer-readable medium, that retains instructions for executing functions associated with electrical components **710** and **712**, wherein any of electrical components **710** and **712** may exist either within or outside memory **720**.

FIG. **8** is a flow chart representation of a wireless communication methodology **800**. At box **802**, an indication of one of several codebooks is received, such as from a base station. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, each of the several codebooks may be stored in a memory and the received indication of one of the codebooks may be used to retrieve the indicated codebook from the memory.

At box **804**, channel state information feedback may be determined using the indicated codebook. The channel state information feedback may include several feedback information elements, such as the wideband and/or subband feedback parameters discussed above and shown in Tables 1-3. In one example, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. For example, at least two of the feedback information elements, such as the wideband and/or subband feedback parameters, may be assigned a different number of resource blocks (RBs), as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. For example, at least one of the feedback information elements may include a column permutation set, such as one of the column permutation sets shown in Table 1. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas, such as the feedback parameter b_0 discussed above. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements.

At box **806**, the channel state information feedback may be transmitted, such as to a base station **110**. The transmitted channel state information feedback may include the feedback information elements.

FIG. **9** is a block diagram representation of a portion of a wireless communication apparatus **900**. Module **902** is provided for receiving an indication of one of several codebooks. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, each of the several codebooks may be stored in a memory and the received indication of one of the codebooks may be used to retrieve the indicated codebook from the memory. The channel state information feedback may include several feedback information elements. Module **904** is provided for determining channel state information feedback using the indicated codebook. Module **906** is provided for transmitting the channel state information feedback, such as to a base station **110**. The transmitted channel state information feedback may include the feedback information elements.

FIG. **10** is a block diagram of a system **1000** that facilitates implementing a structured codebook, according to an embodiment. System **1000** includes functional blocks that may represent functions implemented by a processor, software, or combination thereof (e.g., firmware), wherein system **1000** includes a logical grouping **1002** of electrical components that may act in conjunction. As illustrated, logical grouping **1002** may include an electrical component for receiving an indication of one of several codebooks **1010**, an electrical component for determining channel state information feedback using the indicated codebook **1012**, and an electrical component for transmitting the channel state information feedback. For example, each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F, and the indication of the codebook may include less information than the codebook itself. In another aspect, channel state information feedback may be transmitted to a base station **110**. The channel state information feedback may include feedback information elements. In one example, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements. Additionally, system **1000** may include a memory **1020**, such as a non-transitory computer-readable medium, that retains instructions for executing functions associated with electrical components **1010**, **1012**, and **1014**, wherein any of electrical components **1010**, **1012**, and **1014** may exist either within or outside memory **1020**.

FIG. **11** is a flow chart representation of a wireless communication methodology **1100**. At box **1102**, a codebook is selected from several codebooks in accordance with an antenna characteristic, such as a transmit antenna configuration. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F.

At box **1104**, an indication of the selected codebook is transmitted to a UE **120**. In one example, the indication of the selected codebook may include less information than the codebook itself. At box **1106**, feedback information elements are received from the UE **120**. At least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements.

FIG. **12** is a block diagram representation of a portion of a wireless communication apparatus **1200**. Module **1202** is provided for selecting a codebook from several codebooks in

accordance with an antenna characteristic, such as a transmit antenna configuration. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. Module **1204** is provided for transmitting an indication of the selected codebook to a UE **120**. In one example, the indication of the selected codebook may include less information than the codebook itself. Module **1206** is provided for receiving feedback information elements from the UE **120**. At least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements.

FIG. **13** is a flow chart representation of a wireless communication methodology **1300**. At box **1302**, an indication of one of several codebooks is received from a base station. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, each of the several codebooks may be stored in a memory and the received indication of one of the codebooks may be used to retrieve the indicated codebook from the memory.

At box **1304**, feedback information elements may be determined using the indicated codebook. At least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements. At box **1306**, the feedback information elements may be transmitted to the base station **110**.

FIG. **14** is a block diagram representation of a portion of a wireless communication apparatus **1400**. Module **1402** is provided for receiving an indication of one of several codebooks from a base station. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, each of the several codebooks may be stored in a memory and the received indication of one of the codebooks may be used to retrieve the indicated codebook from the memory. The channel state information feedback may include several feedback information elements. Module **1404** is provided for determining feedback information elements using the indicated codebook. At least two of the feedback information elements may be associated with a different subband granularity. Module **1406** is provided for transmitting the feedback information elements to the base station **110**.

FIG. **15** is a flow chart representation of a wireless communication methodology **1500**. At box **1502**, a codebook is selected from several codebooks in accordance with an antenna characteristic, such as a transmit antenna configuration. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F.

At box **1504**, an indication of the selected codebook is transmitted to a UE **120**. In one example, the indication of the selected codebook may include less information than the codebook itself. At box **1506**, feedback information elements are received from the UE **120**. At least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. The base station may use the indicated subset of precoder column vectors to determine one or more precoders for precoding a signal. Alternatively, or in addition, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements.

FIG. **16** is a block diagram representation of a portion of a wireless communication apparatus **1600**. Module **1602** is provided for selecting a codebook from several codebooks in accordance with an antenna characteristic, such as a transmit antenna configuration. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. Module **1604** is provided for transmitting an indication of the selected codebook to a UE **120**. In one example, the indication of the selected codebook may include less information than the codebook itself. Module **1606** is provided for receiving feedback information elements from the UE **120**. At least one of the feedback information elements may indicate a selection of a subset of precoder column vectors, such as a column permutation set. Alternatively, or in addition, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feedback information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements.

FIG. **17** is a flow chart representation of a wireless communication methodology **1700**. At box **1702**, an indication of one of several codebooks is received from a base station. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, each of the several codebooks may be stored in a memory and the received indication of one of the codebooks may be used to retrieve the indicated codebook from the memory.

At box **1704**, feedback information elements may be determined using the indicated codebook. At least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Alternatively, or in addition, at least two of the feedback information elements may be associated with a different subband granularity, as discussed above. Alternatively, or in addition, at least one of the feed-

back information elements may indicate a phase offset between two groups of transmit antennas. In this example, the first group of transmit antennas may be [0, 1, . . . , m], and the second group of transmit antennas may be [m+1, m+2, . . . Ntx−1], wherein Ntx is the total number of the transmit antennas, and m corresponds to the at least one feedback information elements. At box **1706**, the feedback information elements may be transmitted to the base station **110**.

FIG. **18** is a block diagram representation of a portion of a wireless communication apparatus **1800**. Module **1802** is provided for receiving an indication of one of several codebooks from a base station. Each of the codebooks may be associated with one of several antenna characteristics, such as the transmit antenna configurations illustrated in FIGS. **4**A-F. In one example, the indication of the selected codebook may include less information than the codebook itself. For example, each of the several codebooks may be stored in a memory and the received indication of one of the codebooks may be used to retrieve the indicated codebook from the memory. The channel state information feedback may include several feedback information elements. Module **1804** is provided for determining feedback information elements using the indicated codebook. At least one of the feedback information elements may indicate a selection of a subset of precoder column vectors. Module **1806** is provided for transmitting the feedback information elements to the base station **110**.

FIG. **19** is a flow chart representation **1900** of a method of wireless communication. At operation **1902**, parameters are received, e.g., at a base station **110**. At operation **1904**, a set of precoders based on the received parameters is constructed. At step **1906**, a signal is precoded using the set of precoders. At step **1908**, the precoded signal is transmitted, e.g., from a base station **110** to a UE **120**. At least one of the parameters is allocated a number of subband resource blocks based on a transmit antenna configuration, e.g., the assignments shown in Tables 2 and 3 for parameters a_0, b_0, c_0, c_1, d_1, d_2, and d_3.

FIG. **20** is a diagrammatic representation of an apparatus for wireless communication. Module **2002** is provided for receiving parameters. Module **2004** is provided for constructing a codebook based on the received parameters. Module **2006** is provided for precoding a signal using the codebook. Module **2008** is provided for transmitting the precoded signal. At least one of the parameters is allocated a number of subband resource blocks based on a transmit antenna configuration.

It is understood that the specific order or hierarchy of steps in the processes disclosed is an example of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged while remaining within the scope of the present disclosure. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

The word "exemplary" is used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects or designs.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein (e.g., identifiers, assigners, transmitters and allocators), may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, multiple microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

In one or more exemplary embodiments, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or encoded as one or more instructions or code on a computer-readable medium. Computer-readable media includes computer storage media. Storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such computer-readable media may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to carry or store desired program code in the form of instructions or data structures and that may be accessed by a computer. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present disclosure. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the disclosure. Thus, the present disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

In view of the exemplary systems described supra, methodologies that may be implemented in accordance with the disclosed subject matter have been described with reference to several flow diagrams. While for purposes of simplicity of explanation, the methodologies are shown and described as a series of blocks, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methodologies described herein. Additionally, it should be further appreciated that the methodologies disclosed herein are capable of being stored on an article of manufacture to facilitate transporting and transferring such methodologies to computers. The term article of

manufacture, as used herein, is intended to encompass a computer program accessible from any computer-readable device, carrier, or media.

What is claimed is:

1. A method for wireless communication, comprising:

receiving a plurality of channel phase feedback information elements from a user equipment, at least two of the plurality of channel phase feedback information elements being associated with a different subband granularity, and the at least two of the plurality of channel phase feedback information elements being assigned a different number of resource blocks according to the different subband granularity.

2. The method of claim **1**, further comprising:

determining downlink scheduling based on at least one of the plurality of channel phase feedback information elements; or

determining downlink precoding based on at least one of the plurality of channel phase feedback information elements.

3. The method of claim **1**, wherein at least one of the plurality of channel phase feedback information elements indicates a phase offset between two groups of transmit antennas.

4. The method of claim **3**, wherein a first group of the two groups of transmit antennas includes antennas [0, 1, . . . , m], and a second group of the two groups of transmit antennas includes antennas [m+1, m+2, . . . , Ntx−1], wherein Ntx is a total number of the transmit antennas, and m corresponds to the at least one of the plurality of channel phase feedback information elements.

5. An apparatus for wireless communication, comprising:

a memory unit; and

at least one processor coupled to the memory unit, the at least one processor being configured to receive a plurality of channel phase feedback information elements from a user equipment, at least two of the plurality of channel phase feedback information elements being associated with a different subband granularity, and the at least two of the plurality of channel phase feedback information elements being assigned a different number of resource blocks according to the different subband granularity.

6. The apparatus of claim **5**, in which the at least one processor is further configured:

to determine downlink scheduling based on at least one of the plurality of channel phase feedback information elements; or

to determine downlink precoding based on at least one of the plurality of channel phase feedback information elements.

7. The apparatus of claim **5**, wherein at least one of the plurality of channel phase feedback information elements indicates a phase offset between two groups of transmit antennas.

8. The apparatus of claim **7**, wherein a first group of the two groups of transmit antennas includes antennas [0, 1, . . . , m], and a second group of the two groups of transmit antennas includes antennas [m+1, m+2, . . . , Ntx−1], wherein Ntx is a total number of the transmit antennas, and m corresponds to the at least one of the plurality of channel phase feedback information elements.

9. A method for wireless communication, comprising:

determining a plurality of channel phase feedback information elements using a codebook of the plurality of codebooks, at least two of the plurality of channel phase feedback information elements being associated with a different subband granularity, and the at least two of the plurality of channel phase feedback information elements being assigned a different number of resource blocks according to the different subband granularity; and

transmitting the plurality of channel phase feedback information elements to a base station.

10. The method of claim **9**, wherein at least one of the plurality of channel phase feedback information elements indicates a phase offset between two groups of transmit antennas.

11. The method of claim **10**, wherein a first group of the two groups of transmit antennas includes antennas [0, 1, . . . , m], and a second group of the two groups of transmit antennas includes antennas [m+1, m+2, . . . , Ntx−1], wherein Ntx is a total number of the transmit antennas, and m corresponds to the at least one of the plurality of channel phase feedback information elements.

12. An apparatus for wireless communication, comprising:

a memory unit; and

at least one processor coupled to the memory unit, the at least one processor being configured:

to determine a plurality of channel phase feedback information elements using a codebook of the plurality of codebooks, at least two of the plurality of channel phase feedback information elements being associated with a different subband granularity, and the at least two of the plurality of channel phase feedback information elements being assigned a different number of resource blocks according to the different subband granularity; and

to transmit the plurality of channel phase feedback information elements to a base station.

13. The apparatus of claim **12**, wherein at least one of the plurality of channel phase feedback information elements indicates a phase offset between two groups of transmit antennas.

14. The apparatus of claim **13**, wherein a first group of the two groups of transmit antennas includes antennas [0, 1, . . . , m], and a second group of the two groups of transmit antennas includes antennas [m+1, m+2, . . . , Ntx−1], wherein Ntx is a total number of the transmit antennas, and m corresponds to the at least one of the plurality of channel phase feedback information elements.

15. A non-transitory computer-readable medium for wireless communication having program code recorded thereon, the program code being executed by a processor and comprising:

program code to receive a plurality of channel phase feedback information elements from a user equipment, at least two of the plurality of channel phase feedback information elements being associated with a different subband granularity, and the at least two of the plurality of channel phase feedback information elements being assigned a different number of resource blocks according to the different subband granularity.

16. The non-transitory computer-readable medium of claim **15**, further comprising:

program code to determine downlink scheduling based on at least one of the plurality of channel phase feedback information elements; or

program code to determining downlink precoding based on at least one of the plurality of channel phase feedback information elements.

17. The non-transitory computer-readable medium of claim **15**, wherein at least one of the plurality of channel phase

feedback information elements indicates a phase offset between two groups of transmit antennas.

18. The non-transitory computer-readable medium of claim **17**, wherein a first group of the two groups of transmit antennas includes antennas 0, 1, . . . , m, and a second group of the two groups of transmit antennas includes antennas m+1, m+2, . . . , Ntx−1, wherein Ntx is a total number of the transmit antennas, and m corresponds to the at least one of the plurality of channel phase feedback information elements.

19. A non-transitory computer-readable medium for wireless communication having program code recorded thereon, the program code being executed by a processor and comprising:

program code to determine a plurality of channel phase feedback information elements using a codebook of the plurality of codebooks, at least two of the plurality of channel phase feedback information elements being associated with a different subband granularity, and the at least two of the plurality of channel phase feedback information elements being assigned a different number of resource blocks according to the different subband granularity; and

program code to transmit the plurality of channel phase feedback information elements to a base station.

20. The non-transitory computer-readable medium of claim **19**, wherein at least one of the plurality of channel phase feedback information elements indicates a phase offset between two groups of transmit antennas.

21. The non-transitory computer-readable medium of claim **20**, wherein a first group of the two groups of transmit antennas includes antennas 0, 1, . . . , m, and a second group of the two groups of transmit antennas includes antennas m+1, m+2, . . . , Ntx−1, wherein Ntx is a total number of the transmit antennas, and m corresponds to the at least one of the plurality of channel phase feedback information elements.

* * * * *